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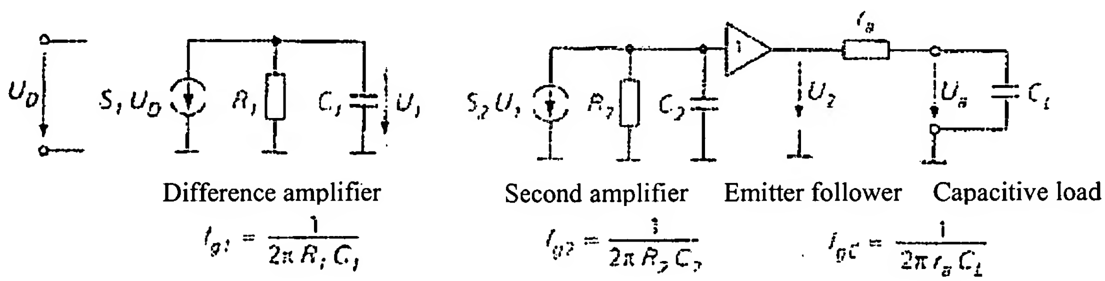


Fig. 5.42. Operational amplifier with capacitive load. In a fully corrected amplifier of the 741 class, f_{g1} = 10 Hz and f_{g2} = 1 MHz

The method of operation of input correction can also be understood in the Bode diagram in Fig. 5.41. At high frequencies, only k = 1/10 of the output signal is fed back and k therefore has the same value as it otherwise would during amplification of A = 1/k = 10. The input noise of the amplifier is actually amplified with this value; for this reason, 1/k is also referred to as noise gain. By input correction, the critical frequency is shifted into a region with greater phase margin, without increasing amplification in so doing.

The frequency response correction at the input can support the internal correction, but never replace it; it is therefore used in partially corrected amplifiers. In non-inverting amplifiers, the input correction does not function as well, since it then depends on the source resistance, which lies in series with R_k.

Capacitive Load

If a capacitive load C_l is connected at the output of an operational amplifier, an additional low pass with limit frequency f_{gC} is produced, together with the output resistance r_a, which is shown in Fig. 5.42. Operational amplifiers with a simple emitter follower at the output have output resistances (of the unstabilized amplifier) in the range of $r_a \approx 1\ k\Omega$, in a Darlington circuit and in HF operational amplifiers, it is generally less than 100 Ω. If the load capacitance is low (C_l < 100 pF), the additional limit frequency f_{gC} lies above the second limit frequency of the amplifier; the phase margin is then only slightly reduced. At larger load capacitances, the additional limit frequency drops below the second limit frequency; this case is shown in Fig. 5.43. It is apparent that the phase shift above f_{gC} becomes so large, that the circuit oscillates during stronger negative feedback. In order to arrive at stable operation, an additional frequency response correction is required [5.3].

Since commercial operational amplifiers are generally corrected internally, it is not possible to subsequently reduce the lowermost limit frequency f_{g1}. However, an additional correction can also be added externally by means of the input correction. We already demonstrated this possibility in Fig. 5.41. Since

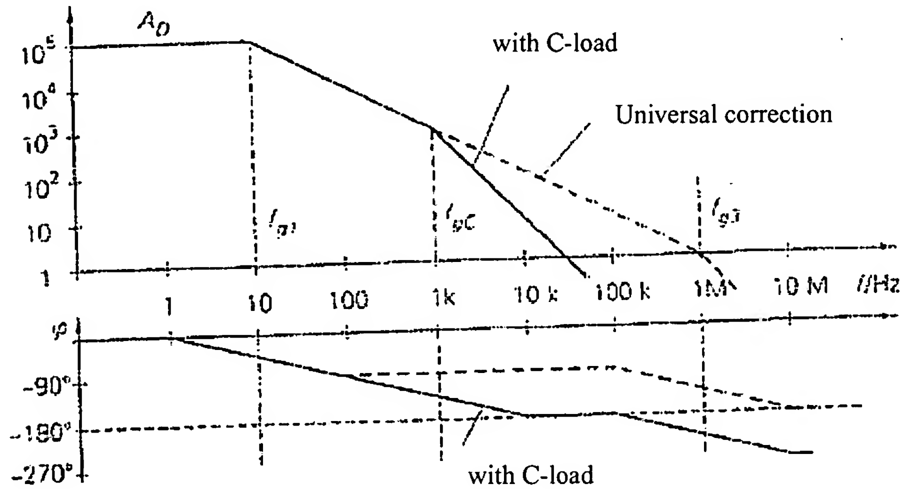


Fig. 5.43. Effect of a capacitive load on a fully corrected operational amplifier

amplification at the second limit frequency f_{gC} = 1 KHz still amounts to 1000 in the example in Fig. 5.43, the loop gain had to be reduced by this factor by input correction. Considerable bandwidth would be lost on this account.

It is more favorable to connect an insulation resistance, as in Fig. 5.44, in front of the capacitive load. At high frequencies, in which the load capacitor represents a short circuit, only a voltage divider from r_a and R_{iso}, which causes no phase lagging, lies at the output of the amplifier. In the Bode diagram in Fig. 5.45, it is apparent that the trend of the phase, in comparison with Fig. 5.43, does not change up to 1 kHz, but, above it, approaches the unloaded case. At the critical frequency $f_k = f_{g2}$ = 100 kHz, a phase margin of 90° is obtained; it determines the transient response of the circuit. It is then unimportant that the phase reserve is lower at low frequencies. The special case is present here, in that the phase reserve is reduced with weaker negative feedback: at an amplification A = 10, the critical frequency lies at 10 kHz; the phase reserve there is only 45°.

The dimensioning will be further explained on a numerical example. An amplifier with a no-load output

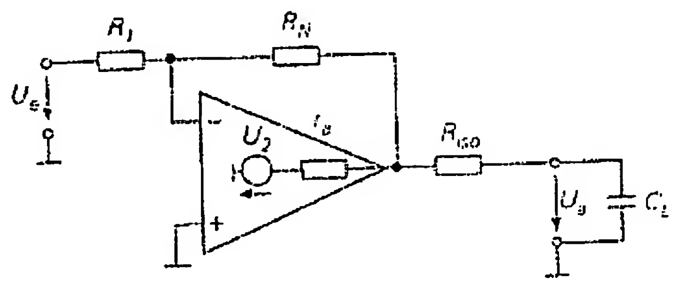


Fig. 5.44. Insulation resistance for phase correction in a capacitive load.

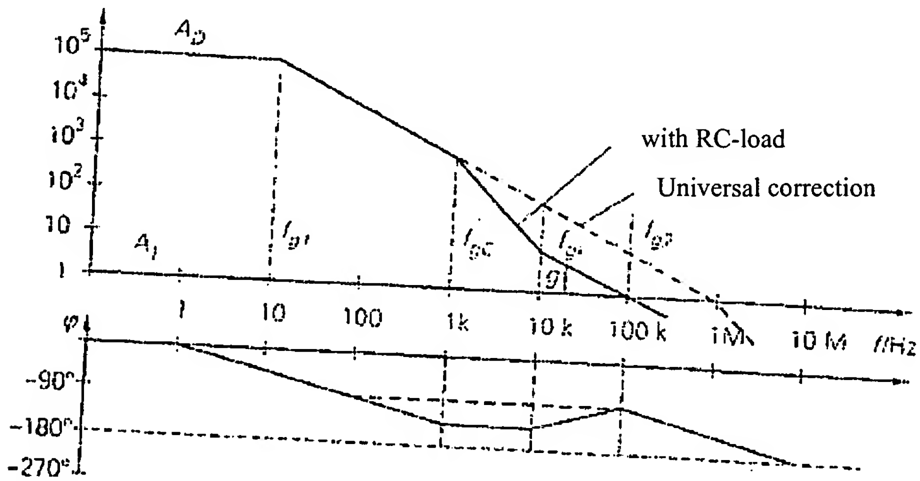


Fig. 5.45. Back-rotation of the phase shift above f_{gk} by the insulation resistance.

resistance of $r_a = 1\ \text{k}\Omega$ should be loaded at the output a capacitance of $C_l = 160$ nF. A limit frequency of

$$f_{gC} = \frac{1}{2\pi r_a C_l} = \frac{1}{2\pi\, 1\text{k}\Omega\, 160\text{nF}} = 1\,\text{kHz} \tag{5.35}$$

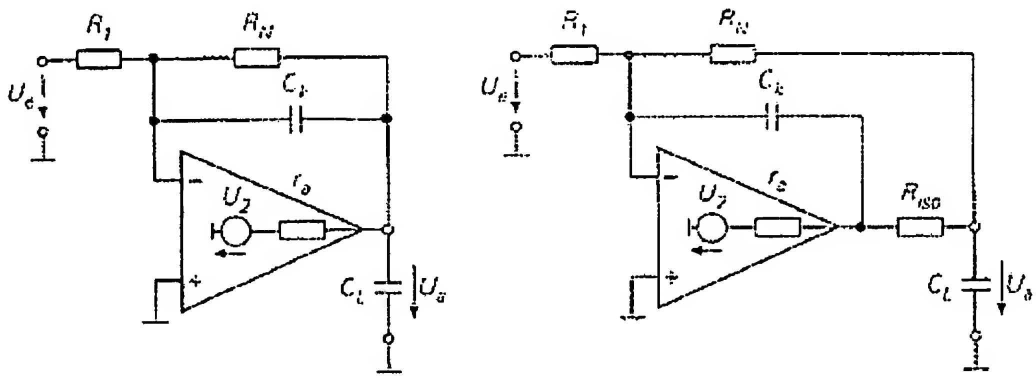
is obtained from this.
In order for the phase shift caused by the load, up to the critical frequency $f_{g2} = 100$ kHz, to be broken down, we choose, according to Fig. 5.45, $f_{gk} = 10$ kHz. With (5.35), it then follows

$$R_{iso} = \frac{1}{2\pi f_{gk} C_l} = \frac{f_{gC}}{f_{gk}} r_a = \frac{1\,\text{kHz}}{10\,\text{kHz}} 1\,\text{k}\Omega = 100\,\Omega \tag{5.36}$$

In order to obtain the largest possible bandwidth, R_{iso} can be chosen somewhat smaller. Because of this, on the one hand, the limit frequency of the output low pass not lying in the negative feedback loop is increased. On the other hand, because of the reduction of phase reserve, an increase in amplification develops according to Fig. 5.33, which can compensate for the drop caused by the low pass $R_{iso}C_l$ in a certain frequency range.

For many applications, the use of an insulation resistance according to Fig. 5.44 is a disadvantage, since the load is not operated at low resistance. The conventional wiring around the capacitor C_k in fig. 5.46a can then be expanded. It can compensate for the phase lagging caused by the load. For dimensioning, it is enlarged until the desired transient response or the desired frequency response is obtained.

In obstinate cases, an insulation resistance according to Fig. 5.46b can additionally be introduced. In order for the intended trend of the output voltage to be produced on the load capacitor, the voltage U_l at the amplifier output must lead. If this voltage is fed back via the correction capacitor C_k, the stabilizing effect is amplified [5.1].



a Correction with C_k b Correction with C_k and R_{iso}

Fig. 5.46. Operation of a capacitive load with phase correction.

Internal Load Correction

In order to make operational amplifiers as user-friendly as possible, manufacturers take the trouble to use universal internal correction for capacitive loads. The ideal is to amplify the existing correction at capacitive loads. For this purpose, the R_kC_{k2} element in Fig. 5.47 is used, which bridges the emitter follower at the output. At a weaker load, virtually no voltage drop occurs on r_a; the RC element therefore remains without effect. At high load, the additional correction capacitor C_{k2} lies almost parallel to C_{k1}. In this way a situation can be achieved in which an operational amplifier does not independently oscillate, even at capacitive loads; the transient response, however, is generally only weakly dampened, so that additional measures are required [5.2] [5.4].

Two-pole Frequency Response Correction

During frequency response correction at capacitive loads, we saw in Fig. 5.45 that the phase reserve becomes very small in a certain frequency range. This is tolerable, since only the phase reserve at the critical frequency f_k is decisive for the transient response. Amplification of an operational amplifier for phase correction can therefore also [text cut off]

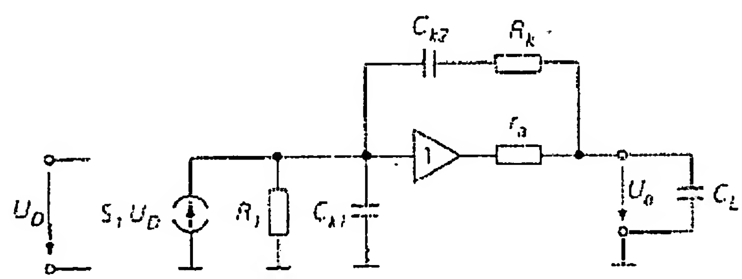


Fig. 5.47. Internal correction for capacitive load